Acoustic Measurements of Tiny Optically Active Bubbles in the Upper Ocean

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LONG-TERM GOALS

In this project, which is closely linked to a separate project where the goal is to measure wave induced bubble clouds and their effect on radiance in the upper ocean (N000140710754), we intend to address the disturbing fact that despite the fundamental importance of optical backscatter in the ocean it is still not possible to explain more than 5 to 10 percent of the particulate backscattering in the ocean based on known constituents even during periods with no active wave breaking (Terrill & Lewis, 2004). One hypothesis is that very small bubbles that have been stabilized by surfactants may be responsible for part of the “missing” backscatter. The long-term goal of this project is to develop an acoustic tool to test this hypothesis and if these small bubbles are present, to determine their concentration and size distribution.

OBJECTIVES

The main objective is to modify an existing instrument design to allow for *in situ* measurements of bubbles over a wide range of bubble radii from approximately 500 micrometer at the upper end and down to less than 5 micrometer. We will push the technology to its limit with a goal of reaching bubble radii as small as 1 micrometer. Based on the outcome of this investigation we will decide whether this modified design will be incorporated into all the sensors to be used in the N000140710754 project. The bubble distributions will be measured under a range of different wind and wave conditions from Scripps Pier and R/P FLIP in field campaigns during January and September 2008 and in 2009.

One interesting aspect of these particular measurements will be to investigate how these tiny bubbles develop from the breaking wave bubble size distributions and how the distribution and number density of these bubbles evolve following storms and periods with and without wind and wave breaking.

APPROACH

Different acoustical techniques utilizing the resonant behaviour of small bubbles have for some time been used to obtain bubble size distributions in the ocean (e.g., Vagle and Farmer, 1998). These approaches make use of the fact that bubbles will resonate at a frequency proportional to their size and that the resulting scattering cross section of these bubbles is orders of magnitude higher than the corresponding geometrical scattering cross section from a particle of the same size, i.e. the bubbles

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have minimal damping of the incoming acoustical waves and therefore have high Q factors. (This fact also makes acoustical techniques less prone to effects from other particles in the sampling volume, a problem that often becomes critical in optical bubble sizing techniques).

The freely flooding acoustical resonator, pioneered by H. Medwin allows bubble size measurements through inversion of the bulk acoustic properties of the fluid (Farmer, Vagle & Booth, 1998; 2005). A reverberant cavity between two parallel plates is ensonified with broadband noise producing multiple resonant modes that are detected with a hydrophone. Excitation of the bubbles modifies the bulk complex sound speed of the fluid leading to attenuation and frequency changes of the resonator response. By utilizing the broadband sensitivity of the resonator both resonant and off-resonant contributions to acoustic properties over a wide frequency range provide data that are inverted to recover the distribution of bubbles of different sizes within the cavity. The instrument operates at low signal intensity, justifying application of linear acoustical theory to the inversion. Near-continuous transmission of sound into the cavity avoids uncertainties in the time dependent acoustic response of bubbles to short pulses and multiple reflections of the reverberant signal increase the effective signal-to-noise of the device.

We are building on our present acoustical resonator technology developed over a number of years with support from ONR to measure open ocean bubbles with radii between 15 and 500 micrometer using acoustical frequencies between 4kHz and 200kHz (Farmer, Vagle & Booth, 1998; Vagle & Farmer, 1998; Farmer, Vagle & Booth, 2005). The frequency spacing of the resonant peaks in the resonator depends on the size of the resonant cavity and is approximately 6 kHz in the current design. A numerical model of the operation of these devices combined with laboratory experiments show that the characteristics of their operation depend on the size of the cavity, the thickness and density of the reflecting plates, the piezoelectric film used to generate and receive the acoustical signals and the input electrical signals.

By increasing the acoustical frequency towards 10MHz the potential range of the resonator will be extended toward bubbles with radii ~1 μm as shown in Figure 1.

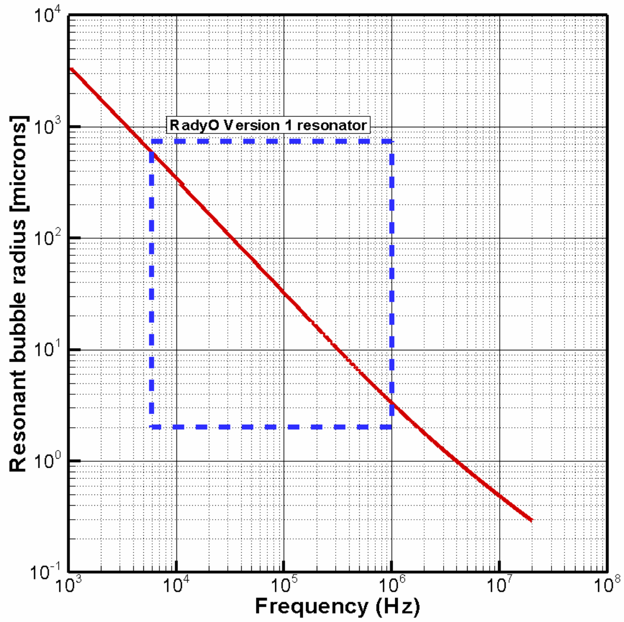

Figure 1. Resonant bubble radii as function of the acoustical frequency insonifying the bubbles. The present frequency range and corresponding bubble radius range are identified by the blue dotted lines. The present resonator design can measure bubbles with radii between approximately 3.5μm and 500μm.

WORK COMPLETED

Our present version of the 'new' resonator is capable of acoustical frequencies up to 1MHz, corresponding to a lower bubble radius of approximately 3.5 μm (Figure 1). The size of the electronics has been reduced and the instrumentation now has all sound generation and receive-electronics close to the resonator transducers with only digitized data being transmitted back to the logging computer. This significantly improves the signal to noise ratio of the system and reduces the number of vulnerable cables required from 4 to 1.

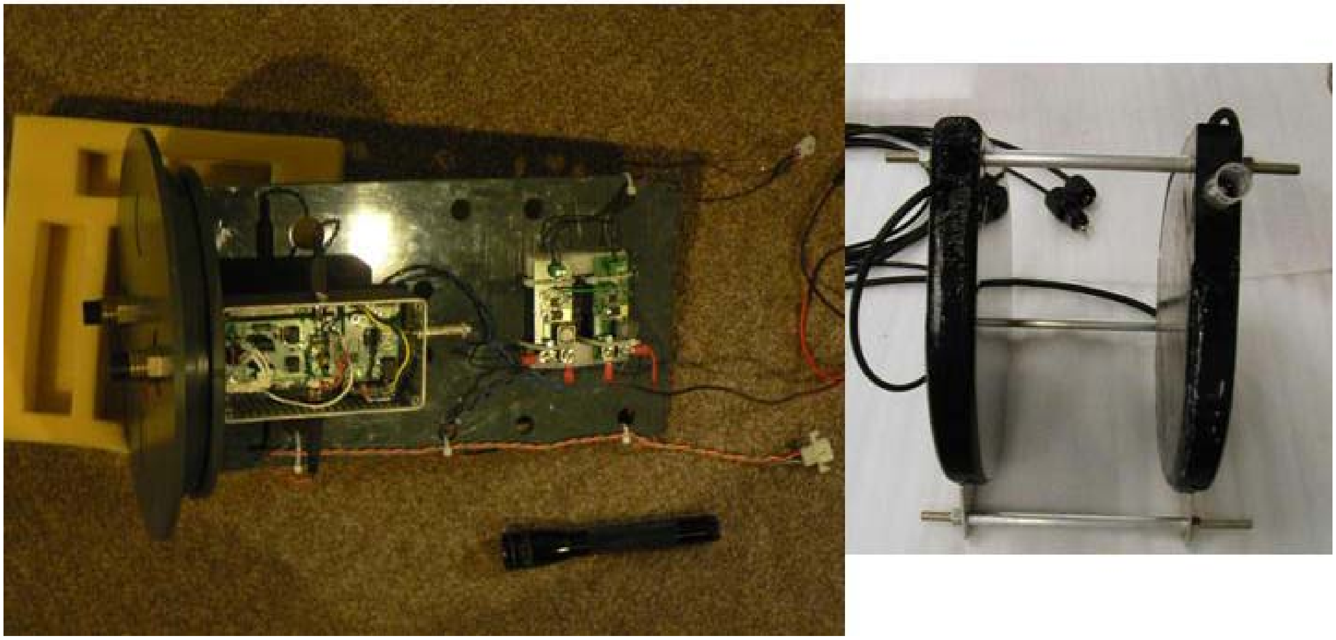

Figure 2. The RadyO acoustical resonator (right photo) with the associated sound generation, receive electronics and digitizer (left photo) capable of measuring bubble size distributions over a radius range from about 3.5 to 500μm.

The first field testing and use of the MHz resonator will take place during field experiments at the Martha's Vineyard Coastal Observatory (MVCO) in October 2007 and then during the first RadyO field experiment at Scripps Pier where the instrument will be deployed with a MASCOT and an IOP profiler to compare the acoustical bubble measurements with optical measurements planned as part of RadyO. The system we have developed is capable of frequencies as high as 10MHz and over the coming months we will be experimenting with higher and higher frequencies approaching this limit.

RELATED PROJECTS

The development of a high-frequency, tiny bubble detection device will be utilized in the closely associated RadyO project N000140710754. In this project the goal is to measure and model bubble injection and radiance fluctuations in the upper ocean during wave-breaking conditions. However, the instrumentation developed here will also support the interpretation of most of the other RadyO projects when bubbles are present. The instrument will be also be tested and used during the upcoming ONR sponsored SPACE07 experiment at MVCO (N000140710759).

REFERENCES

Farmer, D.M., S. Vagle, and A.D. Booth, 1998, A free flooding acoustical resonator for measurement of bubble size distributions, *J. Atmos. Oceanic Technol.*, 15(5), 1132–1146.

Farmer, D.M., S. Vagle, and A.D. Booth, 2005, Reverberation Effects in Acoustical Resonators for Bubble Measurements, *J. Acous. Soc. Am.*, 118, 2954-2960.

Terrill, E. & M. Lewis, 2004, Tiny bubbles: and overlooked optical constituent. Oceanography, 11, 11.

Vagle S., and Farmer D.M., 1992, The measurement of bubble size distributions by acoustical backscatter. *J. Atm. and Oceanic Technology* 49(9), 630-644.

Vagle, S., and Farmer D.M., 1998, A comparison of four methods for bubble size and void fraction measurements, *IEEE J. of Oceanic Engineering*, 211-222.